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Endoscopy: Developments in Optical Instrumentation

Max Epstein

The endoscope, whose name was derived from two Greek words—endon, within, and skopein, to view—has become an important and versatile tool in medicine. It allows for remote viewing, photography, biopsy, and even surgery have ancillary channels for passage of air, water, and implements such as biopsy forceps, cytology brushes, or various surgical tools that can be remotely controlled. The manner in which the image is conveyed determines whether the

Summary. Optical fibers transmit high-intensity illumination for viewing internal organs and tissue. Remote viewing is obtained by relays of lenses or graded-index-of-refraction rods in rigid endoscopes and by precisely aligned fiber-optic bundles in flexible fiberscopes. Endoscopy is considered for routine examinations, such as in colonoscopy. Lasers are used as surgical tools through endoscopes for cutting and coagulation. They may also be used to provide illumination for the efficient transmission of light through thin optical fibers.

on organs and tissue, since it can be passed through natural openings and cavities in the human body or through the skin, that is, percutaneously. Consequently, new medical procedures such as bronchoscopy, gastroscopy, proctosigmoidoscopy, and so forth, have evolved. While most of these procedures are part of particular medical specialties, the principles of operation and basic features of the various instruments used are similar.

The background, physical principles, and applications of the endoscope have been described (*1*). Briefly, an endoscope embodies the means for transmitting light to illuminate the internal space being viewed and for conveying the image of the distal object back to the viewer. In addition, most endoscopes

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instrument is rigid or flexible; for example, the transmission of images by a relay of lenses requires that the endoscope remain rigid, while the use of a bundle of precisely aligned optical fibers makes a flexible endoscope, often referred to as a fiberscope. For the transmission of light for illumination of the distal objects, nearly all current endoscopes use optical fibers.

Optical Fibers for Illumination

Figure 1A shows the trajectories of rays entering a glass rod of refractive index n_1. Ray I_1, upon refraction at the entry face, is totally reflected at the wall of the glass rod and propagates along the rod by repeatedly bouncing off the wall until it refracts and emerges at the exit face. On the other hand, most of ray I_2 does not reflect at the wall of the rod but, instead, refracts and escapes through it. All rays entering at an angle smaller than α_0 such that they impinge on the wall at an angle greater than the critical angle α_c, will be trapped in the rod and continue to its exit face. This feature of light guiding holds even if the glass rod is bent at a radius substantially larger than the diameter of the glass rod, and the angle α_0 determines the aperture or the cone of light accepted and transmitted through such an optical fiber. Since any contact with the outside wall of the rod or fiber will affect and impair the total reflection and, thus, the trapping of light rays, it is customary to enclose the glass rod or fiber in a tube of glass of lower refractive index $n_2 < n_1$ (Fig. 1B). The interface between the two glasses causes the reflections to be nearly lossless; however, the critical angle is greater, and the numerical aperture (NA) of the clad or step-index optical fiber is smaller than in the case of an unclad rod and is given by

$$NA = n_0 \sin\alpha_0 = (n_1^2 - n_2^2)^{1/2}$$

where n_0 is the refractive index of the surrounding medium and is equal to 1.0 for air and 1.33 for water.

When drawn in a furnace to a diameter of 25 or 50 micrometers, the clad optical fiber is quite flexible and can be bent to radii of less than 1 centimeter. In order to transmit adequate light, the thin optical fibers are gathered in a bundle with the ends bound and polished. Since relatively short lengths of a few meters are involved, the resultant attenuation of light is far below that available in the current low-loss fibers that are used in communication systems. Low-loss fibers have been developed that can efficiently transmit wide-band communication signals over large distances without amplification and with immunity to electromagnetic interference. An important feature that distinguishes the applications in illumination from those in communications is the need for a high-aperture fiber. Glass fibers with a core made of flint glass (n_1 = 1.62) and soda lime for the cladding (n_2 = 1.52) have an aperture of 0.56 which, in air, renders a cone of light of 68°. Since most imaging systems employ distal lenses and thus provide wideangle visualization, it is important to provide adequate illumination over the entire area to be viewed. Indeed, some illumination fiber bundles can also be equipped with a light-diverging distal lens.

An important consideration in the choice and preparation of optical fibers for illumination is the spectral response of light transmission. The faithful rendition of color in viewing and photography depends on the spectral content of the white-light illumination. This is of particular significance in medical applications where the diagnosis of disease depends on the appearance and color of organs and tissue. Ultraviolet illumination is a significant tool in the fluorescence method of diagnosis, and there is a need for special fibers such as optical fibers made of fused quartz that will efficiently transmit ultraviolet light. Since fused quartz has the lowest refractive index of all glasses, the cladding must be chosen from other materials such as plastics.

Light sources. Conventional light sources for endoscopes include tungsten projection lamps and mercury and xenon high-pressure arc lamps in quartz glass enclosures, with lifetimes ranging from 25 to 1000 hours. Color temperatures of tungsten sources vary from 2800 to 3500 K, low color temperatures that make the illumination appear yellow. The light entering the fiber is attenuated by bulk absorption and scattering losses. With the selective light transmission of fibers characterized by a relatively higher attenuation in the short wavelengths, that is, at the blue end of the spectrum, the appearance of objects can be erroneous. Other losses can be minimized; for example, Fresnel losses due to reflections at the end surfaces of the fiber can be reduced by antireflection coating.

The General Electric Marc-300 is an arc lamp that is widely used in film projectors. It has tungsten electrodes and indium tri-iodide vapor in a quartz enclosure and provides light intensity at a color temperature of about 5500 K. Unlike tungsten-filament lamps, which can be operated directly with alternating current and require, at most, a transformer and rheostat, the arc lamps need special high-voltage regulated power supplies. The Marc-300 arc lamp has a 6600-volt starting potential and a current of 7.7 amperes with a 37.5-volt direct-current supply. Both filament and arc lamps produce heat directly or by conversion of visible light to infrared through absorption. Special provisions must therefore be made to dissipate and divert large amounts of heat. This is done by means of special filters or reflectors with a dichroic coating. Various schemes have been used to maximize the light intensity delivered from the source to the fiber or fiber bundle and to obtain uniform illumination at the distal end of the fiber. For example, a special reflecting mirror in the form of an ellipsoid of revolution has the light source and the fiber input at the focal points with the major axis of the ellipsoid at an angle to the light-receiving fiber (*2*). However, it should be noted that light from conventional as opposed to laser sources cannot be focused or concentrated onto areas smaller than their original size without considerable loss of the luminous flux.

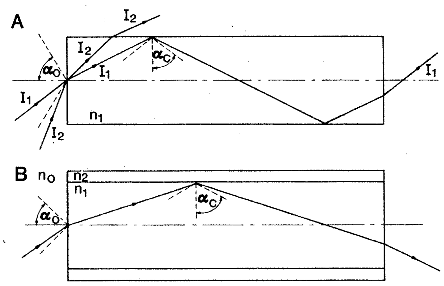


Fig. 1. Ray trajectories in (A) glass rod of refractive index n_1, and (B) same glass rod clad in a glass tubing of refractive index n_2.

The high-intensity light sources required to deliver adequate illumination to and through the optical fibers cause the fibers to become extremely hot. In the case of fiber bundles, the amount of heat generated at the proximal end of the fibers requires that they not be bonded by epoxy but be fused together. In some cases this may also apply to the distal end if enough heat is conducted through the fiber or is generated by absorption of light in the fiber. Such undesirable cases should be avoided. After all, one of the main objectives in the use of illumination fibers is to keep the heat of the light source away from the object being illuminated. Indeed, the early applications of optical fibers were referred to as "cold light" illumination.

Laser illumination. The design of miniature endoscopes limits the space available to accommodate optical fibers for illumination, but adequate illumination through a small number of fibers can be obtained with laser, rather than with conventional incoherent, light sources. The coherent laser light is limited only by diffraction and can be focused to an area or spot diameter of about 1 μm. Also, since lasers produce light only at specific wavelengths, there is no extraneous infrared radiation to be suppressed. Although a typical laser produces monochromatic light, which does not render color information from the illuminated object, there are a number of systems that lase at various wavelengths simultaneously. For example, when a krypton-ion laser with a special broadband mirror was used, it was possible to obtain a 1-millimeter-diameter beam of white light composed of 476-nanometer (blue), 568-nm (green), and 647-nm (red) wavelengths. The beam was then focused onto and passed through a single optical fiber, 1 meter long and 85 μm in diameter (*3*).

A detrimental side effect in the use of lasers as illuminators is the appearance of speckle. It is due to the coherent nature of laser light which, as a result of wave interference, produces a nonuniform distribution of light over the illuminated area; in the case of multiple-wavelength laser light, the speckles appear as spots of different colors. The use of diffusers, such as a Teflon screen, considerably reduces the available illumination. A far more efficient method of reducing speckle is to vibrate the optical fiber slightly, at about 30 hertz, anywhere along its length, thereby disrupting the coherence of the wave and, thus, creating the perception of diffused light. Since at any instant of time the speckle effect does remain, the frequency of vibrations should be increased in the case of high-speed photography.

Even though light of nearly any color, including white, can be produced with three colors, a larger number of constituent colors may be required to obtain a faithful color image. An efficient method of multicolor lasing is obtained by rotating a multisector mirror perpendicular to the lasing direction. This produces white light by sequential generation of laser light at various wavelengths (*4*).

The transmission of visible light through optical fibers is selectively attenuated, mostly in the blue range, resulting in yellow illumination and a distorted color rendition of the image. This color distortion is even more significant in fibers made of plastics. The laser illuminator can be used advantageously with plastic optical fibers since an efficient means of color balancing is provided; also, compensation must be made for distortions in the transmission through the illumination fiber or fiber bundle as well as for additional color-selective attenuation of light through the imaging system (*5*).

Rigid Endoscopes

For the past hundred years the standard endoscope has been a multielement telescope consisting of a sequence of field and relay lenses. The periodic train of lenses allows the image of an object to be transmitted through a small-diameter instrument without reducing the field of view. Illumination of the viewed object is provided either by a miniature lamp located at the distal end of the instrument or, in the case of recent devices, by a bundle of optical fibers. The effectiveness of the instrument depends on the illumination delivered to the object to be viewed and the amount of light entering and transmitted through the imaging system of the endoscope. The latter can be improved considerably by replacing the air spaces between the lenses with glass. In this case, the lens relay, known as the Hopkins rod-lens system, consists of long glass rods and short air spaces. An increase in the refractive index of the glass-filled imaging system and in the diameter of the lens aperture, produced by eliminating the need for spacers, causes the light-transmitting capacity of the Hopkins telescope to increase substantially over the earlier versions that had glass-lens relays. This instrument, manufactured by Karl Storz in Germany, is available in diameters as small as 2.7 mm and includes a 1.6-mm-diameter rod-lens imaging system and a bundle of optical fibers for illumination. A similar instrument, which also uses rod lenses, is manufactured by American Cystoscope Makers, Inc. (ACMI). It has a diameter of about 2 mm and lengths that exceed 30 cm. The endoscopes can be designed to view the object in any direction, and they provide straight forward, forward oblique, lateral, or retrospective views. The field of view can range from 60° to 100°.

The rigid endoscope is used chiefly to examine organs and tissue that are accessible through the natural openings and channels in the human body. It was first used in cystoscopy, where it became possible to visually perform transurethral surgery of the bladder and prostate. Other types of endoscopes include the bronchoscope, esophagoscope, hysteroscope, laryngoscope, and rectoscope. The rigid endoscope has also been used through the skin and cavity walls to visualize the kidneys (nephroscope) and the pleural (thorascope), peritoneal (laparoscope), and joint (arthroscope) cavities, as well as in prenatal examinations (amnioscope).

Percutaneous endoscopy has been further advanced by the introduction of the graded-index-of-refraction glass rod, developed by the Nippon Sheet Glass Company in Japan. The lens-like glass fiber, named Selfoc, is a light guide with a refractive index that varies parabolically with its radius and is capable of transmitting images through a single fiber of a specific length. Its resolving power, which depends on the field angle, ranges from 200 to 400 line pairs per millimeter, and is affected by the irregularity of the parabolic profile of the index of refraction, the flatness of the terminal surfaces, and chromatic aberration (*6*). As is the case with the step-index fibers, an imaging fiber with a graded index of refraction should have a large numerical aperture, that is, a wider spread in the refractive index than is usually the case in optical fibers used in communication systems. (In communication systems the quadratic variation of the refractive index with radius of the fiber is very useful in that it prevents the spreading of the optical signal derived from a conventional light source and thus allows for the transmission of short pulses or high data rates.) At present, the imaging graded-index fiber is fabricated in sizes ranging from 0.7 to 2 mm in diameter and various lengths that provide both erect and inverted images. Depending on the length of the fiber, an object located at a distance from one end of the rod will form an image beyond its other end surface and, thus, the fiber will function as a biconvex lens. Imaging rods up to 20 cm long have been constructed.

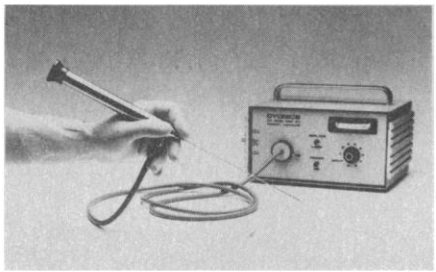


Fig. 2. Needlescope with a 1.7-mm-diameter and 15-cm-long needle, consists of a 1-mm-diameter graded-index-of-refraction lens and lens rod and a fiberoptic bundle for illumination. [Manufactured by Dyonics, Inc., Woburn, Massachusetts]

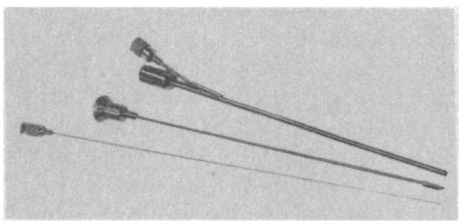


Fig. 3. Needlescope accessories for fetal blood sampling (*8*). The oval cannula accommodates the miniature endoscope and the 27-gage hypodermic needle for simultaneous taking of blood and visualization. The tool in the center is the trocar with a sharp tip for inserting the instrument by percutaneous puncture. [Manufactured by Dyonics, Inc., Woburn, Massachusetts]

Needle endoscopes, 1.7 and 2.2 mm in diameter and 10 to 20 cm long, are available from Dyonics, Inc., in Woburn, Massachusetts (Fig. 2). They are used extensively to examine the knees and small joints of the body and in laparoscopy, thoracoscopy, peritoneoscopy, and fetoscopy. The latter is developing into an important technique of fetal visualization. It can be particularly significant in cases where the two most current techniques of indirect fetal evaluation, amniocentesis and ultrasound, are not adequate to determine serious inherited disorders or congenital abnormalities. In addition to diagnosis, this method of visual examination of the fetus can improve procedures such as intrauterine transfusions and lead to possible treatment of the fetus (*7*). Figure 3 shows the accessories used with the needlescope to obtain fetal blood samples under direct vision (*8*).

An even smaller imaging structure can be obtained by drawing a large number of optical fibers in a furnace, in a manner that preserves their alignment. A cross section of such a multifiber, which is 0.5 mm in diameter and contains 11,000 fibers, each 4.2 μm in diameter, is shown on the cover. The honeycomb pattern represents the boundaries of the individual fibers and is superimposed on the image, which appears as if viewed through a screen. Recently, a miniature, rigid endoscope was designed for direct visualization and photography of root canals in dental patients (Fig. 4). The endoscope is 24 cm long and has a stainless steel needle, 4 cm long and 0.91 mm in diameter, that can be inserted into a root canal. The 0.5-mm-diameter imaging multifiber terminates at three plano-convex distal lenses of the same diameter and is surrounded by a 0.1-mm-thick annular layer of illumination fibers. The distal three-lens system provides over 75° of solid-angle view and remains in sharp focus for objects at distances of 1 mm to infinity. A similar device, used to visualize the posterior segment of the eye, is 0.7 mm in diameter and contains only the imaging multifiber.

Flexible Fiberscopes

The aligned multifiber shown on the cover is drawn as a fused glass rod and therefore remains rigid. When constructed of individual fibers, each about 10 μm in diameter, the imaging bundle is flexible allowing for small bending radii. The aligned individual fibers are bound together at their ends while the rest of the fibers along the length of the bundle remain loose and therefore flexible (Fig. 5).

The fabrication of flexible imaging fiber bundles involves precise winding of the optical fibers on a highly polished and uniform cylinder whose circumference determines the length of the imaging bundle. The aligned fibers can be wound directly from the fiber-drawing furnace or from a separate spool of nonaligned fibers. When the entire bundle is produced in a single winding process, similar to a coil, an overhang of fibers wound on the outer layers develops after the structure is removed from the winding cylinder. Such overhang can be eliminated by winding single or small numbers of fiber layers and then by cutting them into strips to form the aligned fiber bundle. This process, although more laborious, usually makes the aligned bundle more uniform. Some users find the evenness of the fiber arrangement distracting and prefer the more irregular structure. The effect may be compared to viewing a television image whose horizontal line scan has been accentuated by imperfect interlacing.

The resolution attainable with a perfectly aligned fiberoptic imaging structure is determined by the fiber diameter. For a hexagonal configuration of fibers, the resolution, in optical line pairs per millimeter is at best equal to, and usually slightly less than, 1 to 2 *d*, where *d* is the fiber diameter in millimeters. A simple test of image quality may be obtained by viewing the transmission of a sharp border such as a knife edge. A more quantitative measure of the sharpness of the edges is the optical modulation transfer function, which provides an accurate means of determining the quality of image transmission of aligned optical fibers (*9*).

As is the case with the rigid endoscope, a typical flexible fiberscope includes a bundle of nonaligned fibers for illumination and channels to accommodate tools for biopsy, for aspiration to remove liquids from the region being inspected, and for insufflation of the organ or for injection of clear fluids to permit better visualization. Diameters of typical instruments vary between 5 and 15 mm. The fiberoptic endoscope can be made as long as necessary since the light losses in most fibers made of glass cores and cladding are negligible over distances of several meters. Numerous accessories are available for recording images, including cameras such as the 35-mm single-lens reflex, 8- and 16-mm movie cameras, and color television cameras.

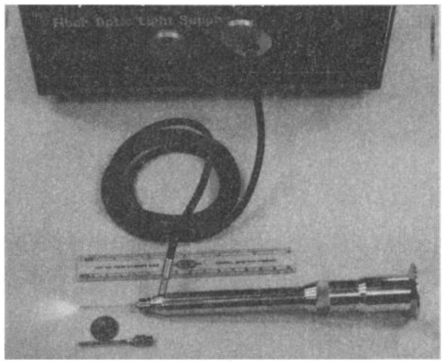


Fig. 4. Miniature endoscope for the visualization of root canals.

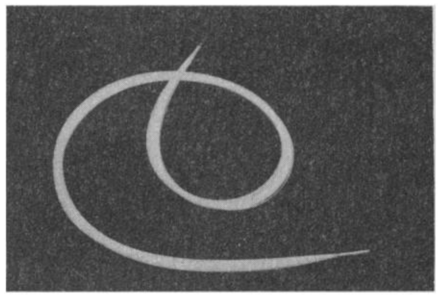


Fig. 5. Flexible fiberoptic imaging bundle.

There are presently four major suppliers of fiberscopes: Olympus Optical Co., Ltd., Machida Endoscopic Co., Ltd., and Fujinon Optical, Inc., in Japan; and ACMI in the United States, which was the first to produce fiberoptic imaging bundles for the Hirschowitz gastroscope (*10*). Most of the fiberscopes use similar optical structures that vary mainly in length, total diameter, maneuverability, and accessories such as biopsy forceps. The diameters of the individual glass fibers in the image-conveying aligned bundle are similar, ranging from 9 to 12 μm.

The use of fiberscopes in medical practice may reduce the complexity of some conventional procedures, but it may also pose problems when extended to include new techniques in diagnosis and surgery. Medical specialists warn against abuses resulting from the use of the instruments by inexperienced practitioners. Nonetheless, when used properly, fiberscopes have been applied safely to obtain biopsies in patients of all ages. Bronchofiberscopes have been used successfully in therapy such as the removal of secretions, or in the early diagnosis of lung cancer, and in visualization into bronchi up to the sixth order. The diagnosis of very small tumors, which contributes to early detection, is performed endoscopically with fluorescence of a hematoporphyrin derivative. The drug is retained preferentially by malignant cells 2 to 4 days after intravenous injection but is cleared from normal cells. The respiratory tract is illuminated with violet light ($\approx$ 400 nm), and the image of the tumor is produced by the fluorescence emission in the red range (600 to 700 nm) of the hematoporphyrin derivative (*11*).

The gastrofiberscope was the first fiberoptic endoscope (*10*). It is usually somewhat larger in diameter than the bronchofiberscope and often contains more elaborate provisions for guiding the instrument. Various versions have been used successfully to diagnose gastric cancers, and probes approximately 1.5 m long were designed to reach the duodenum. Long fiberscopes, up to 1.6 m, with remote control of the guidance have been used in colonoscopy for the inspection of the entire colon. The fiberoptic colonoscope appears to be the first endoscope considered for use in routine examination of the colon in preventive medicine and in the management of postoperative patients.

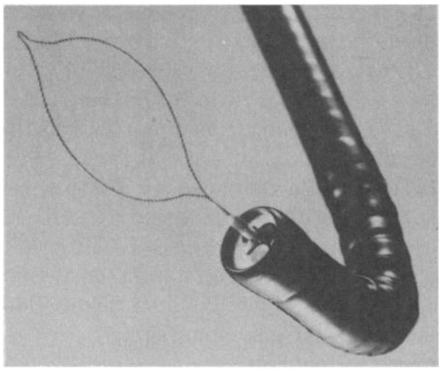
Colonoscopy

Carcinoma of the large bowel is the second leading malignancy. About 112,000 new cases are diagnosed each year, and 52,000 deaths occur in the United States annually. Early detection is important, and the colonoscope is a very important tool for detecting early carcinoma missed by x-ray examinations. Furthermore, removal of benign polyps should lead to a decrease in the incidence of colon carcinoma. Since colonoscopic polypectomy is performed without laparotomy (incision through the abdominal wall) or general anesthesia, the associated morbidity and mortality, in particular in older patients, have been reduced to negligible levels. Thus, use of the colonoscope reduces risk of injury for many elderly patients whose lesions remain benign and allows patients to benefit from the resection of an early or latent malignancy. Figure 6 shows the distal end of an Olympus CF type LB3R colonofiberscope with snares passed through the instrument channel for the removal of polyps by cauterization with the electrically heated wire.

The colon usually assumes a tortuous shape, and the passage of the fiberscope for a complete or partial examination often requires special techniques and skills. For example, a patient may be required to swallow a string, which takes several days, in order to provide a guide along which the colonoscope may be steered and advanced into the colon (*12*). However, once inside the colon, the colonoscope helps to reduce sharp bends and loops of the lumen, as shown in Fig. 7. In most cases, the examination of the colon is performed during withdrawal of the instrument.

Although the available instruments are usually effective in the hands of an experienced endoscopist, perforations of the colon and life-threatening hemorrhages may occur if the examiner attempts to overcome obstacles due to anatomical and pathological variations in the colon. The National Cancer Institute is supporting research to develop aids and techniques to facilitate passage of the colonoscope to the cecum in order to make colonoscopy with flexible fiberscopes a simple and safe procedure.

An experimental miniature fiberscope was developed to aid in the exploration of obstructions that may impede the advancement of the colonoscope. It can also be used to visualize spaces inaccessible to the larger instrument; for example, the terminal ileum can be viewed through the ileocecal valve. This miniature fiberscope, 2.1 m long and slightly under 4 mm in diameter (Fig. 8), includes optical fibers for viewing and illumination, a distal lens system, channels for passage of air and water, and a guidance system. The imaging structure consists of a bundle of aligned 10-μm fibers, which are 1.3 mm in diameter and 2.4 m long, and a distal lens system, 1.45 mm in diameter, which provides a field of view of 63° and depth of focus from 1 mm to infinity. Two 0.5-mm-diameter fiber bundles for illumination are designed to couple to a commercial light source. The guidance is obtained by four wires embedded in a catheter and controlled by a ball-joint handle made by Medi-Tech, Inc., in Watertown, Massachusetts. The two ancillary channels for passage of air and water are each 0.5 mm in diameter. Figure 9 shows the miniature endoscope passed through and protruding 20 cm beyond the large channel of the ACMI, dual-channel colonoscope.



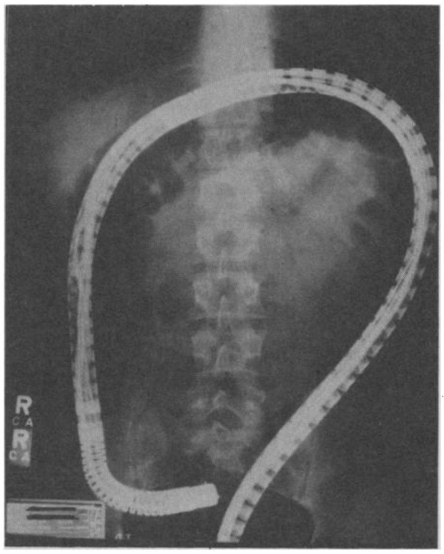


Fig. 6 (left). Distal end of Olympus CF type LB3R colonofiberscope with snares. Fig. 7 (right). Colonoscope passed through the entire colon.

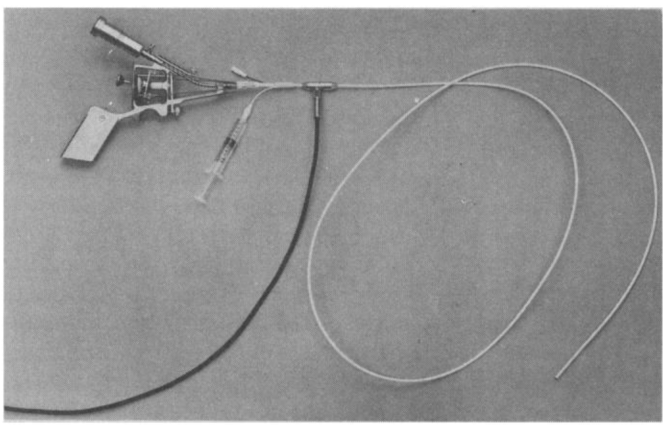


Fig. 8. Long miniature endoscope. [Photograph by Jerry Straus Studios, Chicago, Illinois]

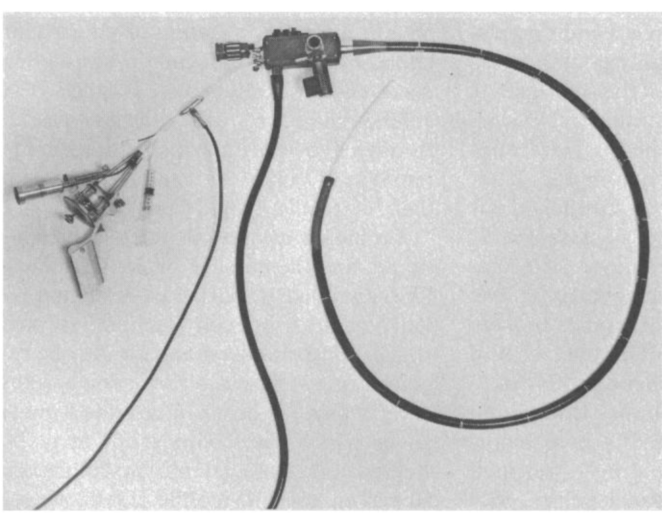


Fig. 9. Miniature endoscope of Fig. 8 passed through the 4-mm channel of a 1.6-m-long ACMI model TX92 colonoscope. [Photograph by Jerry Straus Studios, Chicago, Illinois]

Laser Surgery

The most commonly used lasers in medicine are argon-ion lasers, which emit in the blue-green range of the light spectrum, and neodymium-yttrium-aluminum-garnet (YAG) and CO_2 lasers which radiate at wavelengths of 1.06 and 10.6 μm, respectively. The energy of the CO_2 laser beam is highly absorbed by water and hence by tissue to depths of less than a fraction of a millimeter, thereby functioning as a very effective "light knife." On the other hand, a neodymium-YAG laser beam penetrates into tissue and arteries up to 5 mm and is very useful in coagulating blood and reducing bleeding. The radiation of the argon-ion laser, which operates at a wavelength of about 0.5 μm, is also absorbed by blood.

Argon lasers have been used extensively in ophthalmology for retinal photocoagulation. The beam passes through the cornea, lens, and clear vitreous humor and is absorbed in the fundus oculi. The argon-ion laser has also been used in the endoscopic treatment of bleeding ulcers. A high-power argon laser is coupled through a quartz optical fiber to deliver the highly concentrated laser beam through the ancillary channel of a standard fiberscope (*13*). Auth and his colleagues (*13*) also developed heater- and computer-controlled electrosurgical probes that are introduced through the flexible fiberscope to stop massive bleeding of ulcers by applying both heat and pressure for electrocoagulation (*14*).

The CO_2 laser has been used in medicine for nearly a decade (*15*). The most significant nonendoscopic applications have been in neurosurgery. The CO_2 laser radiation, emitted at a wavelength of 10.6 μm, cannot be transmitted through any of the currently available optical fibers. A pliable optical fiber, made of thallium bromide and thallium bromoiodide in a polymer cladding, has only recently been developed (*16*), and it can transmit the CO_2 laser beam efficiently. Until now, endoscopic surgery with CO_2 lasers has had to be performed through rigidly coupled endoscopes. The CO_2 laser beam is guided through a series of reflecting mirrors located in rotary joints to form an articulate arm of very high precision. For example, the CO_2 laser beam, entering through the lumen of a 4-cm speculum, has been used by Lobraico (*17*) to destroy epithelial changes or dysplasia on the cervix and upper vagina. Andrews (*18*) uses the CO_2 laser with a rigid bronchoscope to remove or reduce obstructing lesions of the trachea and bronchi.

The third most commonly used laser in medicine is the neodymium-YAG. Since its radiation can be transmitted through optical fibers, this laser has been employed endoscopically; for example it has been used to vaporize the interior lining of the uterus to destroy bleeding sites (*19*).

Conclusion

Developments in fiberoptic imaging structures present the greatest challenge to the evolution of the endoscope. The application of endoscopy continues to affect medical procedures and is influencing the training and practice of physicians. Although many endoscopes are sold directly to physicians and can, in principle, be used in office procedures, their widespread application must evolve through stages of safe testing and training in teaching hospitals. New applications for endoscopes and the development of new instruments are the result of collaborative efforts of physicians, life scientists, and engineers. Further advances in this field will be aided by the development of better and simpler methods for acquiring and transferring records (for example, by photography or on video tape); by the development of smaller imaging structures, both flexible and rigid, and safer and more versatile instrument design; and by the application of lasers in surgery. The development of polymeric optical fibers for imaging and of laser illuminators and special waveguides for CO_2 and CO laser transmission are significant factors in the advances in endoscopy. Percutaneous devices should gain wider acceptance and contribute to new techniques in the visual diagnosis and therapy of organs and tissue not accessible through conventional endoscopes. Further developments in hypodermic fiberscopes, similar to those described above for visualization of root canals, may lead to applications such as intralesional delivery of drugs for localized tumor therapy. The history and experience of the past decade indicate that endoscopy and its applications will continue to gain increasing acceptance and utilization in medicine.

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